

## **BACKGROUND OF THE INVENTION**

### **Field of the Invention**

- 5      The present invention relates to a system and a method for handling the laser-  
communication multiplexing in chaotic secure communications, and more  
particularly, for decoding multiplex chaotic laser signals by utilizing a low-pass  
filter to increase the fractal dimension of the chaotic system, so that the decoding  
of the multiplex messages encoded by chaotic behaviors can be achieved. The  
10     disclosure of the present invention can be applied to many kinds of secure  
communication systems.

### **Discussion of the Prior Art**

- 15     The technique of multiplex transmission has been well established in the  
field of conventional laser communications. However, it still lacks effective  
scheme of combining such laser multiplexing to chaotic secure communication  
systems. On the other hands, although it has been addressed that chaotic systems  
can be applied to secure communications, however, the conventional techniques  
20     of simplex-coupled synchronization can only work well in simplex transmission,  
it appeared some difficulties in handling multiplex transmission. The main  
reason can be attributed to the nonlinear interaction among the multiplex laser  
signals, resulting in a superimposed, interfered and complex chaotic system. To  
resolve these tow problems, a low-pass filter is utilized to increase the fractal  
25     dimension of the multiplex chaotic signals, so that the periodicity of these  
chaotic signals will be enhanced. This technique can be used to rebuild the  
multiplexed messages encoded by chaotic behaviors in laser communications.

## **SUMMARY OF THE INVENTION**

It is an object of the present invention to provide a method for handling laser-communication multiplexing in chaotic secure communications. By using a low-pass filter, a chaotic time sequence of lower fractal dimension can be effectively increased to a chaotic time sequence of higher fractal dimensional, so that the  
5 periodicity of the multiplex signals will be enhanced and hence the decoding of messages from the chaotic laser signals become possible.

It is another object of the present invention to provide a method for handling laser-communication multiplexing in chaotic secure communications, wherein the scheme of chaotic secure communications utilizes the behavior of extremely  
10 sensitive dependence on initial conditions and the feature of randomness of the chaotic laser light.

It is another object of the present invention to provide a method for handling laser-communication multiplexing in chaotic secure communications, wherein the scheme of chaotic secure communications is achieved by adjusting the  
15 coupling parameters of the receiver system, so that the chaotic system of the receiver end is simplex coupled to the transmitter end, and thus prohibiting the transmitted messages to be rebuilt by any unauthorized receptor.

## BRIEF DESCRIPTION OF THE DRAWINGS

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FIG. 1 is a block diagram for describing a chaotic sequence generated from a self-pulsating laser diode by adjusting the amplitude and frequency of the externally applied driven ac current;

25 FIG. 2 is a block diagram for illustrating the procedure of synchronizing the chaotic laser signal of the receiver with that of the transmitter;

FIG. 3 is a block diagram for illustrating the use of low-pass filter to decode multiplexed messages encoded by chaotic signals;

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FIG. 4(a) and (b) are the time sequence, Signal(t), of the multiplexed signals and the frequency spectrum of the multiplexed signal obtained by taking FFT to the Signal(t);

FIG. 5(a) and (b) illustrate the output,  $e(t)$ , of the receiver system after chaotic synchronization and the corresponding frequency spectrum after taking FFT to the  $e(t)$ ;

- 5 FIG. 6(a) and (b) show the output,  $y(t)$ , from the low-pass filter of the present invention and the corresponding frequency spectrum after taking FFT to the  $y(t)$ ; and

FIG. 7 is a flowchart for illustrating the scheme of the chaotic secure communication and a comparison between the procedures of the conventional system without using the low-pass filter of the present invention and the system of the present invention with the use of low-pass filter.

## DETAILED DESCRIPTION

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As has been approved by computer experiments and numerical simulations, the system and the method of the present invention is an effective scheme for handling the laser-communication multiplexing in chaotic secure communications, in which the system and the method for encoding and decoding 20 the messages to be multiplexed comprise the following procedures,

1. Proceeding of chaotic behavior of self-pulsating laser diodes.

As shown in FIG. 1, the self-pulsating laser diode 12 is driven by an externally applied ac current,  $I = a + b \sin(2\pi ft)$ , where  $a$ ,  $b$  and  $f$  are the offset 25 current, the amplitude and the frequency of the ac current respectively. By adjusting the amplitude and the frequency of the input ac current, the self-pulsating laser diode will generate a chaotic laser light 13. The reason for this chaotic behavior is the conflict between the frequency of the applied ac current and the natural frequency of the self-pulsating laser diode 12, leading the system 30 to a quasi-period-two behavior. According to the theory of chaos, i.e., quasi-period-two routes chaos, the self-pulsating laser diode 12 will generate chaotic laser signals 13 when the amplitude and frequency of the applied ac current are adjusted appropriately. The chaotic behavior of the laser output can be further

confirmed by Poincaré section, Lyapunov exponent and bifurcation diagram. This chaotic behavior is the most important precondition for encoding the message. Since a chaotic system depends sensitively on initial conditions and exhibits a random behavior, it is very difficult to decode the hidden message in  
5 the chaotic carrier.

2. Synchronization of the simplex-coupled chaotic proceeding.

Synchronization is the most important technique in communication applications. As shown in FIG. 2, the drive chaotic laser signals, which  
10 is detected by photo detector PD(D), and generated by the method described in step 1, from the transmitter end can be simplex-coupled to the response chaotic laser signals PD(R) of the receiver end by arranging same coupling coefficients between transmitter and receiver end. According to our computer experiments and numerical simulations, for a suitable coupling coefficient, the  
15 chaotic sequences of the response and the drive systems will be synchronized. This phenomenon is also the basic principle for utilizing these chaotic behaviors to the applications of secure communications. This synchronization can be further confirmed by using the conditional Lyapunov exponent. The signature of simplex-coupled behavior exhibited between two chaotic systems will prohibit  
20 the transmitted messages being rebuilt by any unauthorized receptor.

3. Proceeding of using simplex asymptotical synchronization principle.

Asymptotical synchronization is the most important technique for recovering the messages encoded by chaotic carrier. By using the simplex asymptotical  
25 synchronization principle, when the chaotic laser light of the transmitter containing messages is delivered to the receiver end, the receiver can reproduce a asymptotical synchronized chaotic laser light. The carried messages can then be rebuilt by taking fast-Fourier transformation (FFT) to the difference between the output signals of the transmitter and the receiver. This technique is well  
30 established for decoding a simplex transmission message. However, for the case of multiplex transmission, due to the complex phenomenon induced by the nonlinear interactions between different multiplex channels, it will appear some difficulties to rebuild the transmitted messages by simply taking FFT to the

synchronized chaotic systems. This can be seen in FIGs. 4(a), 4(b), 5(a) and 5(b). The messages to be multiplexed are shown in FIG. 4(a) and 4(b), which are the time sequences,  $Signal(t)$ , of the messages to be multiplexed and the corresponding frequency spectrum by taking FFT to the  $Signal(t)$ , respectively. The difference,  $e(t)$ , between the output signals of the transmitter and the receiver after synchronization is displayed in FIG. 5(a). However, as shown in FIG. 5(b), the transmitted messages cannot be rebuilt by simply taking FFT to the  $e(t)$ . Therefore, the decoding of multiplexed messages carried by chaotic signals should further utilize the technique described in the following procedure.

#### 4. The use of low-pass filter proceeding.

This procedure is the most important technique for recovering the multiplexed messages encoded by chaotic signals, which is also the major part of the present invention. As shown in FIG. 3, due to the nonlinear interactions among different multiplex channels, the multiplex signals will interfere and superimpose with each other. Thus, the multiplexed messages cannot be fully recovered, if the conventional method as described in step 3 was used to decode them. To resolve this problem, this invention introduces a low-pass filter 21 to process the chaotic signals after synchronization. As illustrated in FIG. 7, first, the difference,  $e(t)$ , between the output of the transmitter and the receiver is sent into the low-pass filter. The low-pass filter can be described by the following differential equation,

$$25 \quad \frac{dy(t)}{dt} = -\alpha y(t) + e(t)$$

where  $\alpha$  is the parameter of the low-pass filter and  $y(t)$  is the signal after low-pass-filtering. According our numerical simulations, if the parameter  $\alpha$  is in the range of 0.13-0.97, the original chaotic time sequence of lower fractal dimension will be transferred to a chaotic time sequence of higher fractal dimension. Owing to the higher fractal dimension, the periodicity of these multiplex messages will be emerged and hence the decoding of these

multiplexed messages can be achieved. The effects of the low-pass filter can be seen in FIG. 6(a) and (b). By comparing FIG. 6(b) with FIG. 4(b), it is clear that the multiplexed messages have been rebuilt by taking FFT to the signals after being sent through the low-pass filter of the present invention.

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